

# **CHAPTER 3**

## **ALTERNATING CURRENT GENERATORS**

### **LEARNING OBJECTIVES**

Upon completion of this chapter, you will be able to:

1. Describe the principle of magnetic induction as it applies to ac generators.
2. Describe the differences between the two basic types of ac generators.
3. List the advantages and disadvantages of the two types of ac generators.
4. Describe exciter generators within alternators; discuss construction and purpose.
5. Compare the types of rotors used in ac generators, and the applications of each type to different prime movers.
6. Explain the factors that determine the maximum power output of an ac generator, and the effect of these factors in rating generators.
7. Explain the operation of multiphase ac generators and compare with single-phase.
8. Describe the relationships between the individual output and resultant vectorial sum voltages in multiphase generators.
9. Explain, using diagrams, the different methods of connecting three-phase alternators and transformers.
10. List the factors that determine the frequency and voltage of the alternator output.
11. Explain the terms voltage control and voltage regulation in ac generators, and list the factors that affect each quantity.
12. Describe the purpose and procedure of parallel generator operation.

### **INTRODUCTION**

Most of the electrical power used aboard Navy ships and aircraft as well as in civilian applications is ac. As a result, the ac generator is the most important means of producing electrical power. Ac generators, generally called alternators, vary greatly in size depending upon the load to which they supply power. For example, the alternators in use at hydroelectric plants, such as Hoover Dam, are tremendous in size, generating thousands of kilowatts at very high voltage levels. Another example is the alternator in a typical automobile, which is very small by comparison. It weighs only a few pounds and produces between 100 and 200 watts of power, usually at a potential of 12 volts.

Many of the terms and principles covered in this chapter will be familiar to you. They are the same as those covered in the chapter on dc generators. You are encouraged to refer back, as needed, and to refer

to any other source that will help you master the subject of this chapter. No one source meets the complete needs of everyone.

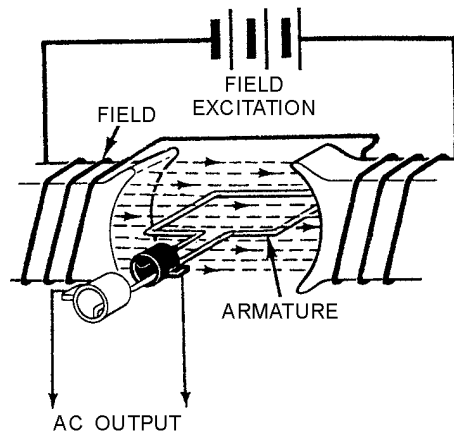
## **BASIC AC GENERATORS**

Regardless of size, all electrical generators, whether dc or ac, depend upon the principle of magnetic induction. An emf is induced in a coil as a result of (1) a coil cutting through a magnetic field, or (2) a magnetic field cutting through a coil. As long as there is relative motion between a conductor and a magnetic field, a voltage will be induced in the conductor. That part of a generator that produces the magnetic field is called the field. That part in which the voltage is induced is called the armature. For relative motion to take place between the conductor and the magnetic field, all generators must have two mechanical parts — a rotor and a stator. The ROTor is the part that ROTates; the STATor is the part that remains STATionary. In a dc generator, the armature is always the rotor. In alternators, the armature may be either the rotor or stator.

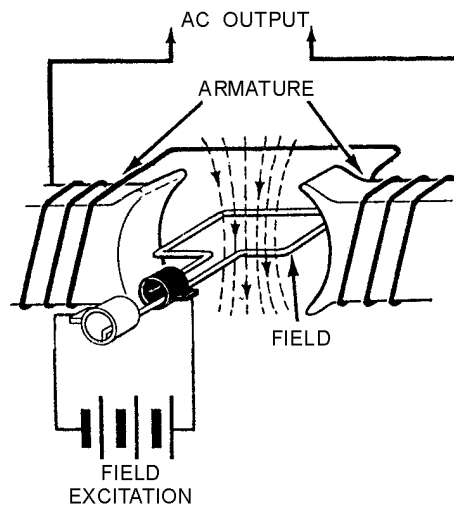
*Q1.* Magnetic induction occurs when there is relative motion between what two elements?

## **ROTATING-ARMATURE ALTERNATORS**

The rotating-armature alternator is similar in construction to the dc generator in that the armature rotates in a stationary magnetic field as shown in figure 3-1, view A. In the dc generator, the emf generated in the armature windings is converted from ac to dc by means of the commutator. In the alternator, the generated ac is brought to the load unchanged by means of slip rings. The rotating armature is found only in alternators of low power rating and generally is not used to supply electric power in large quantities.



**A** ROTATING ARMATURE ALTERNATOR



**B** ROTATING FIELD ALTERNATOR

**Figure 3-1.—Types of ac generators.**

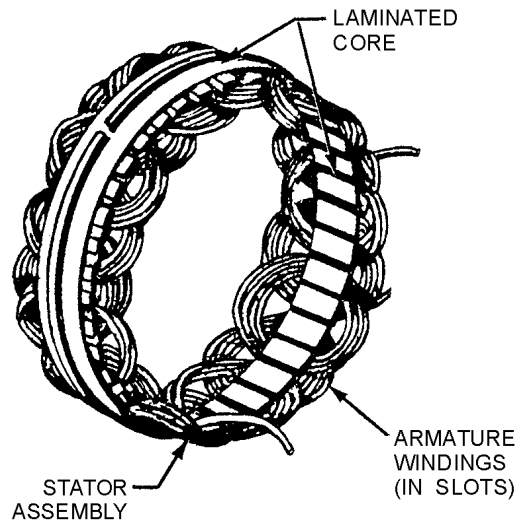
## ROTATING-FIELD ALTERNATORS

The rotating-field alternator has a stationary armature winding and a rotating-field winding as shown in figure 3-1, view B. The advantage of having a stationary armature winding is that the generated voltage can be connected directly to the load.

A rotating armature requires slip rings and brushes to conduct the current from the armature to the load. The armature, brushes, and slip rings are difficult to insulate, and arc-overs and short circuits can result at high voltages. For this reason, high-voltage alternators are usually of the rotating-field type. Since the voltage applied to the rotating field is low voltage dc, the problem of high voltage arc-over at the slip rings does not exist.

The stationary armature, or stator, of this type of alternator holds the windings that are cut by the rotating magnetic field. The voltage generated in the armature as a result of this cutting action is the ac power that will be applied to the load.

The stators of all rotating-field alternators are about the same. The stator consists of a laminated iron core with the armature windings embedded in this core as shown in figure 3-2. The core is secured to the stator frame.



**Figure 3-2.—Stationary armature windings.**

- Q2. What is the part of an alternator in which the output voltage is generated?*
- Q3. What are the two basic types of alternators?*
- Q4. What is the main advantage of the rotating field alternator?*

## **PRACTICAL ALTERNATORS**

The alternators described so far in this chapter are **ELEMENTARY** in nature; they are seldom used except as examples to aid in understanding practical alternators.

The remainder of this chapter will relate the principles of the elementary alternator to the alternators actually in use in the civilian community, as well as aboard Navy ships and aircraft. The following paragraphs in this chapter will introduce such concepts as prime movers, field excitation, armature characteristics and limitations, single-phase and polyphase alternators, controls, regulation, and parallel operation.

## **FUNCTIONS OF ALTERNATOR COMPONENTS**

A typical rotating-field ac generator consists of an alternator and a smaller dc generator built into a single unit. The output of the alternator section supplies alternating voltage to the load. The only purpose for the dc exciter generator is to supply the direct current required to maintain the alternator field. This dc generator is referred to as the exciter. A typical alternator is shown in figure 3-3, view A; figure 3-3, view B, is a simplified schematic of the generator.

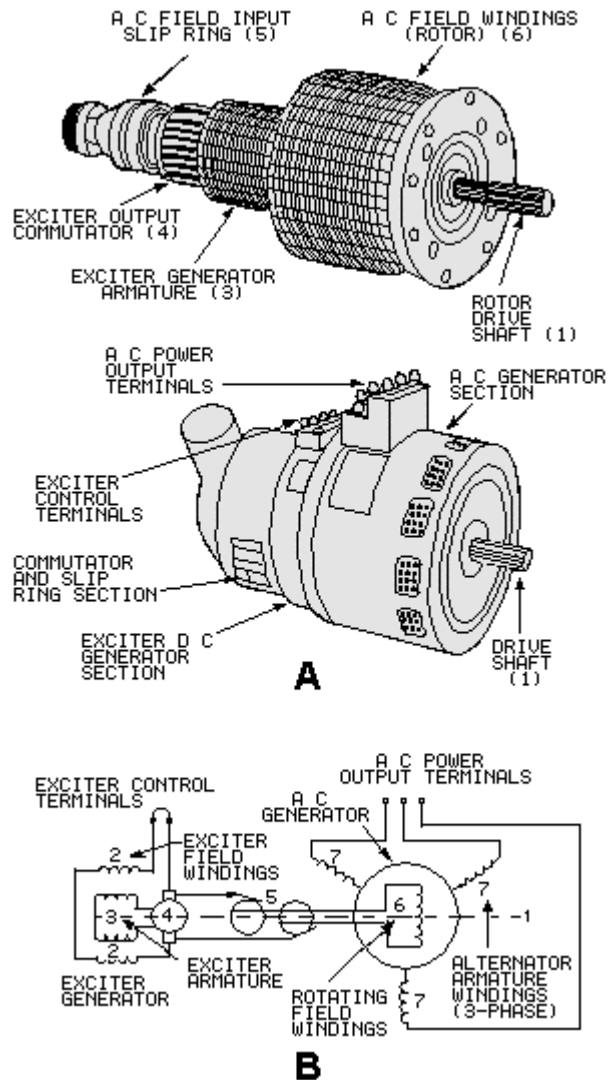


Figure 3-3.—Ac generator pictorial and schematic drawings.

The exciter is a dc, shunt-wound, self-excited generator. The exciter shunt field (2) creates an area of intense magnetic flux between its poles. When the exciter armature (3) is rotated in the exciter-field flux, voltage is induced in the exciter armature windings. The output from the exciter commutator (4) is connected through brushes and slip rings (5) to the alternator field. Since this is direct current already converted by the exciter commutator, the current always flows in one direction through the alternator field (6). Thus, a fixed-polarity magnetic field is maintained at all times in the alternator field windings. When the alternator field is rotated, its magnetic flux is passed through and across the alternator armature windings (7).

The armature is wound for a three-phase output, which will be covered later in this chapter. Remember, a voltage is induced in a conductor if it is stationary and a magnetic field is passed across the conductor, the same as if the field is stationary and the conductor is moved. The alternating voltage in the ac generator armature windings is connected through fixed terminals to the ac load.

*Q5. Most large alternators have a small dc generator built into them. What is its purpose?*

## PRIME MOVERS

All generators, large and small, ac and dc, require a source of mechanical power to turn their rotors. This source of mechanical energy is called a prime mover.

Prime movers are divided into two classes for generators-high-speed and low-speed. Steam and gas turbines are high-speed prime movers, while internal-combustion engines, water, and electric motors are considered low-speed prime movers.

The type of prime mover plays an important part in the design of alternators since the speed at which the rotor is turned determines certain characteristics of alternator construction and operation.

## ALTERNATOR ROTORS

There are two types of rotors used in rotating-field alternators. They are called the turbine-driven and salient-pole rotors.

As you may have guessed, the turbine-driven rotor shown in figure 3-4, view A, is used when the prime mover is a high-speed turbine. The windings in the turbine-driven rotor are arranged to form two or four distinct poles. The windings are firmly embedded in slots to withstand the tremendous centrifugal forces encountered at high speeds.

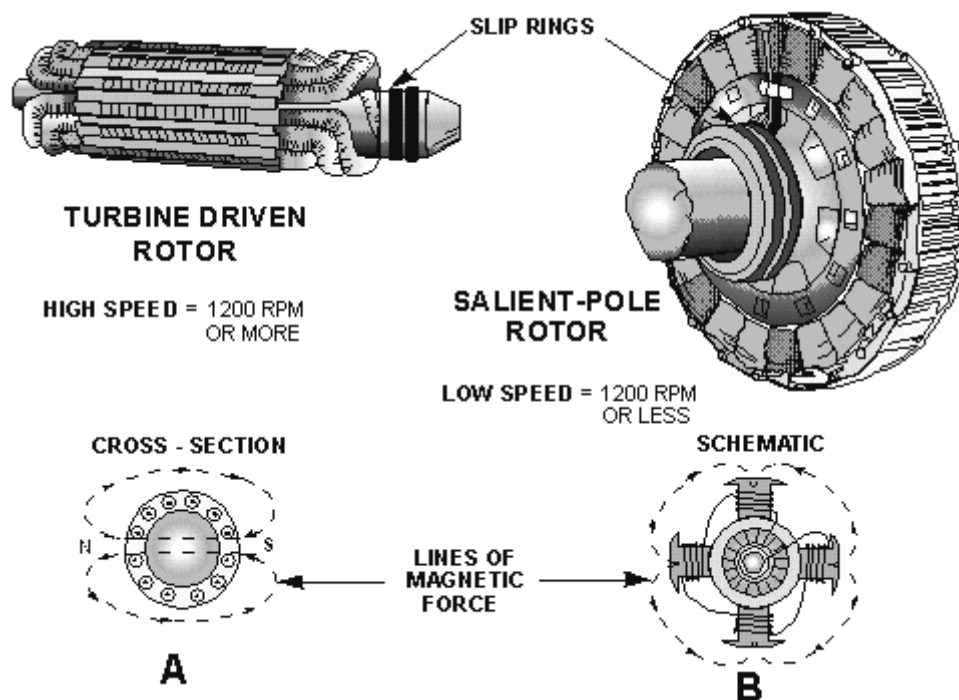


Figure 3-4.—Types of rotors used in alternators.

The salient-pole rotor shown in figure 3-4, view B, is used in low-speed alternators. The salient-pole rotor often consists of several separately wound pole pieces, bolted to the frame of the rotor.

If you could compare the physical size of the two types of rotors with the same electrical characteristics, you would see that the salient-pole rotor would have a greater diameter. At the same number of revolutions per minute, it has a greater centrifugal force than does the turbine-driven rotor. To

reduce this force to a safe level so that the windings will not be thrown out of the machine, the salient pole is used only in low-speed designs.

## ALTERNATOR CHARACTERISTICS AND LIMITATIONS

Alternators are rated according to the voltage they are designed to produce and the maximum current they are capable of providing. The maximum current that can be supplied by an alternator depends upon the maximum heating loss that can be sustained in the armature. This heating loss (which is an  $I^2R$  power loss) acts to heat the conductors, and if excessive, destroys the insulation. Thus, alternators are rated in terms of this current and in terms of the voltage output — the alternator rating in small units is in volt-amperes; in large units it is kilovolt-amperes.

When an alternator leaves the factory, it is already destined to do a very specific job. The speed at which it is designed to rotate, the voltage it will produce, the current limits, and other operating characteristics are built in. This information is usually stamped on a nameplate on the case so that the user will know the limitations.

*Q6. How are alternators usually rated?*

*Q7. What type of prime mover requires a specially designed high-speed alternator?*

*Q8. Salient-pole rotors may be used in alternators driven by what types of prime movers?*

## SINGLE-PHASE ALTERNATORS

A generator that produces a single, continuously alternating voltage is known as a SINGLE-PHASE alternator. All of the alternators that have been discussed so far fit this definition. The stator (armature) windings are connected in series. The individual voltages, therefore, add to produce a single-phase ac voltage. Figure 3-5 shows a basic alternator with its single-phase output voltage.

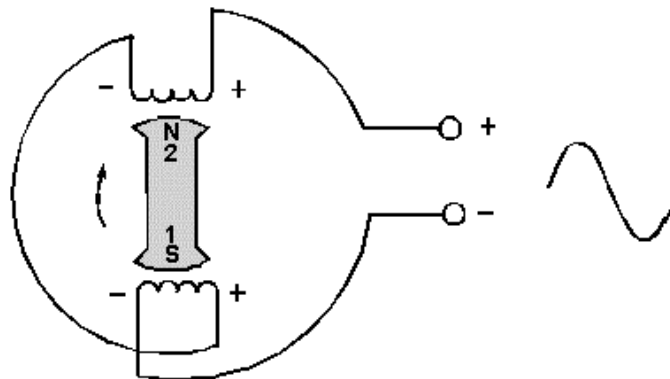


Figure 3-5.—Single-phase alternator.

The definition of phase as you learned it in studying ac circuits may not help too much right here. Remember, "out of phase" meant "out of time."

Now, it may be easier to think of the word *phase* as meaning voltage as in single voltage. The need for a modified definition of phase in this usage will be easier to see as we go along.

Single-phase alternators are found in many applications. They are most often used when the loads being driven are relatively light. The reason for this will be more apparent as we get into multiphase alternators (also called polyphase).

Power that is used in homes, shops, and ships to operate portable tools and small appliances is single-phase power. Single-phase power alternators always generate single-phase power. However, all single-phase power does not come from single-phase alternators. This will sound more reasonable to you as we get into the next subjects.

*Q9. What does the term single phase indicate?*

*Q10. In single-phase alternators, in order for the voltages induced in all the armature windings to add together for a single output, how must the windings be connected?*

## TWO-PHASE ALTERNATORS

Two phase implies two voltages if we apply our new definition of phase. And, it's that simple. A two-phase alternator is designed to produce two completely separate voltages. Each voltage, by itself, may be considered as a single-phase voltage. Each is generated completely independent of the other. Certain advantages are gained. These and the mechanics of generation will be covered in the following paragraphs.

### Generation of Two-Phase Power

Figure 3-6 shows a simplified two-pole, two-phase alternator. Note that the windings of the two phases are physically at right angles ( $90^\circ$ ) to each other. You would expect the outputs of each phase to be  $90^\circ$  apart, which they are. The graph shows the two phases to be  $90^\circ$  apart, with A leading B. Note that by using our original definition of phase (from previous modules), we could say that A and B are  $90^\circ$  out of phase. There will always be  $90^\circ$  between the phases of a two-phase alternator. This is by design.

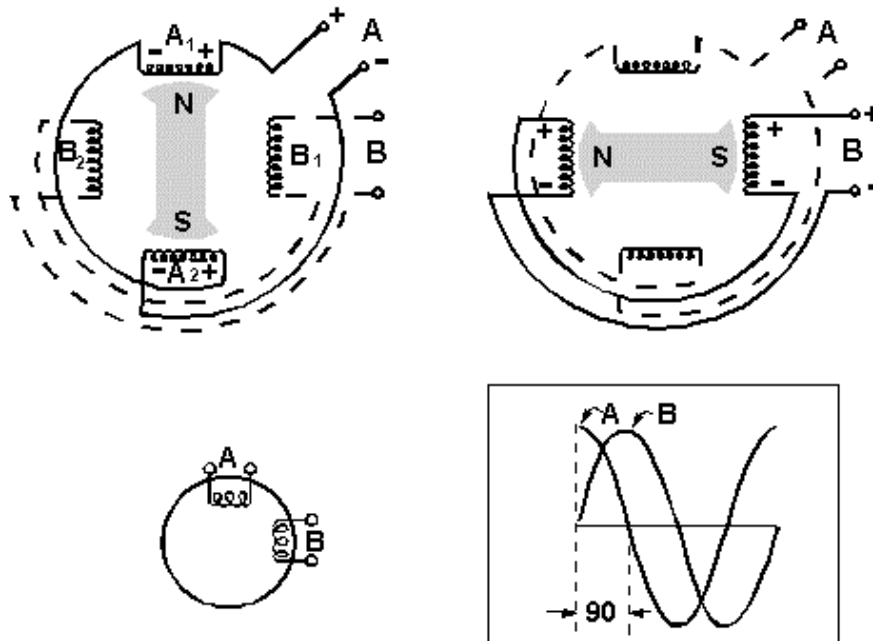


Figure 3-6.—Two-phase alternator.



Now, let's go back and see the similarities and differences between our original (single-phase) alternators and this new one (two-phase). Note that the principles applied are not new. This alternator works the same as the others we have discussed.

The stator in figure 3-6 consists of two single-phase windings completely separated from each other. Each winding is made up of two windings that are connected in series so that their voltages add. The rotor is identical to that used in the single-phase alternator. In the left-hand schematic, the rotor poles are opposite all the windings of phase A. Therefore, the voltage induced in phase A is maximum, and the voltage induced in phase B is zero. As the rotor continues rotating counterclockwise, it moves away from the A windings and approaches the B windings. As a result, the voltage induced in phase A decreases from its maximum value, and the voltage induced in phase B increases from zero. In the right-hand schematic, the rotor poles are opposite the windings of phase B. Now the voltage induced in phase B is maximum, whereas the voltage induced in phase A has dropped to zero. Notice that a 90-degree rotation of the rotor corresponds to one-quarter of a cycle, or 90 electrical degrees. The waveform picture shows the voltages induced in phase A and B for one cycle. The two voltages are 90° out of phase. Notice that the two outputs, A and B, are independent of each other. Each output is a single-phase voltage, just as if the other did not exist.

The obvious advantage, so far, is that we have two separate output voltages. There is some saving in having one set of bearings, one rotor, one housing, and so on, to do the work of two. There is the disadvantage of having twice as many stator coils, which require a larger and more complex stator.

The large schematic in figure 3-7 shows four separate wires brought out from the A and B stator windings. This is the same as in figure 3-6. Notice, however, that the dotted wire now connects one end of B1 to one end of A2. The effect of making this connection is to provide a new output voltage. This sine-wave voltage, C in the picture, is larger than either A or B. It is the result of adding the instantaneous values of phase A and phase B. For this reason it appears exactly half way between A and B. Therefore, C must lag A by 45° and lead B by 45°, as shown in the small vector diagram.

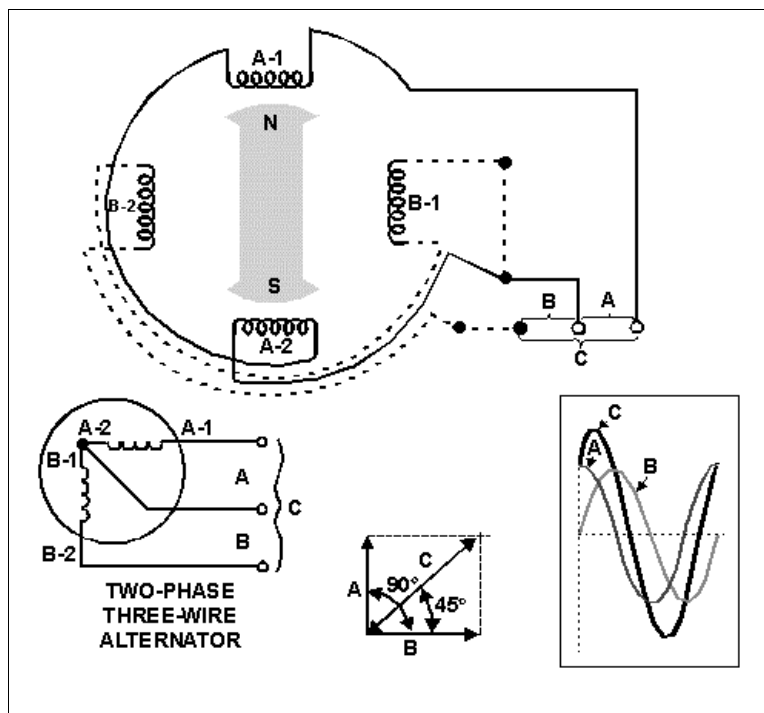


Figure 3-7.—Connections of a two-phase, three-wire alternator output.

Now, look at the smaller schematic diagram in figure 3-7. Only three connections have been brought out from the stator. Electrically, this is the same as the large diagram above it. Instead of being connected at the output terminals, the B1-A2 connection was made internally when the stator was wired. A two-phase alternator connected in this manner is called a two-phase, three-wire alternator.

The three-wire connection makes possible three different load connections: A and B (across each phase), and C (across both phases). The output at C is always 1.414 times the voltage of either phase. These multiple outputs are additional advantages of the two-phase alternator over the single-phase type.

Now, you can understand why single-phase power doesn't always come from single-phase alternators. It can be generated by two-phase alternators as well as other multiphase (polyphase) alternators, as you will soon see.

The two-phase alternator discussed in the preceding paragraphs is seldom seen in actual use. However, the operation of polyphase alternators is more easily explained using two phases than three phases. The three-phase alternator, which will be covered next, is by far the most common of all alternators in use today, both in military and civilian applications.

*Q11. What determines the phase relationship between the voltages in a two-phase ac generator?*

*Q12. How many voltage outputs are available from a two-phase three-wire alternator?*

*Q13. What is the relationship of the voltage at C in figure 3-7 to the voltages at A and B?*

### **THREE-PHASE ALTERNATOR**

The three-phase alternator, as the name implies, has three single-phase windings spaced such that the voltage induced in any one phase is displaced by  $120^\circ$  from the other two. A schematic diagram of a three-phase stator showing all the coils becomes complex, and it is difficult to see what is actually happening. The simplified schematic of figure 3-8, view A, shows all the windings of each phase lumped together as one winding. The rotor is omitted for simplicity. The voltage waveforms generated across each phase are drawn on a graph, phase-displaced  $120^\circ$  from each other. The three-phase alternator as shown in this schematic is made up of three single-phase alternators whose generated voltages are out of phase by  $120^\circ$ . The three phases are independent of each other.

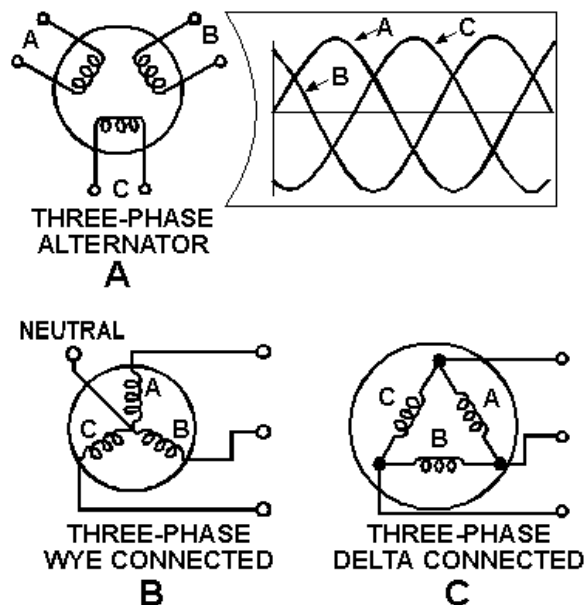


Figure 3-8.—Three-phase alternator connections.

Rather than having six leads coming out of the three-phase alternator, the same leads from each phase may be connected together to form a wye (Y) connection, as shown in figure 3-8, view B. It is called a wye connection because, without the neutral, the windings appear as the letter Y, in this case sideways or upside down.

The neutral connection is brought out to a terminal when a single-phase load must be supplied. Single-phase voltage is available from neutral to A, neutral to B, and neutral to C.

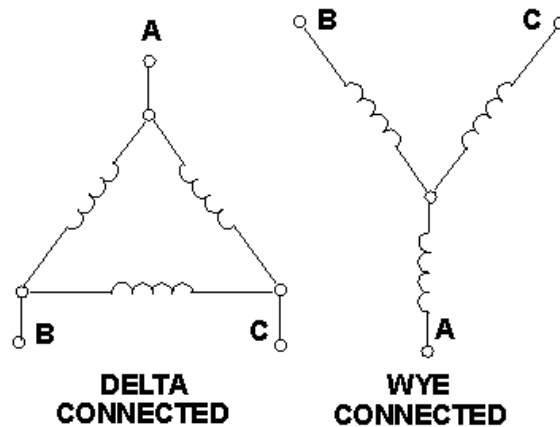
In a three-phase, Y-connected alternator, the total voltage, or line voltage, across any two of the three line leads is the vector sum of the individual phase voltages. Each line voltage is 1.73 times one of the phase voltages. Because the windings form only one path for current flow between phases, the line and phase currents are the same (equal).

A three-phase stator can also be connected so that the phases are connected end-to-end; it is now delta connected (fig. 3-8, view C). (Delta because it looks like the Greek letter delta,  $\Delta$ .) In the delta connection, line voltages are equal to phase voltages, but each line current is equal to 1.73 times the phase current. Both the wye and the delta connections are used in alternators.

The majority of all alternators in use in the Navy today are three-phase machines. They are much more efficient than either two-phase or single-phase alternators.

### Three-Phase Connections

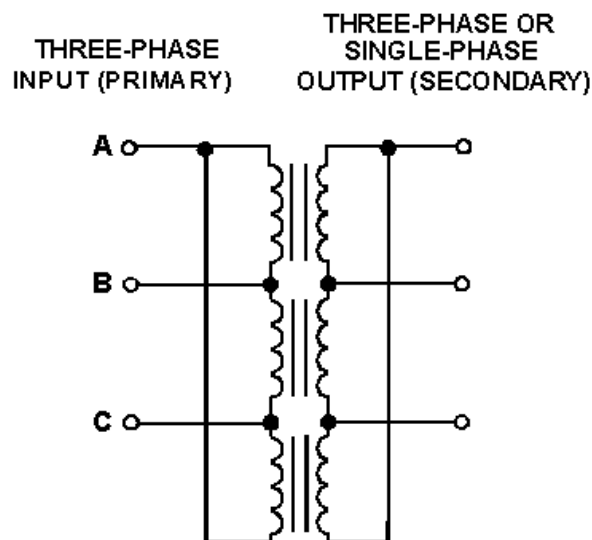
The stator coils of three-phase alternators may be joined together in either wye or delta connections, as shown in figure 3-9. With these connections only three wires come out of the alternator. This allows convenient connection to three-phase motors or power distribution transformers. It is necessary to use three-phase transformers or their electrical equivalent with this type of system.



**Figure 3-9.—Three-phase alternator or transformer connections.**

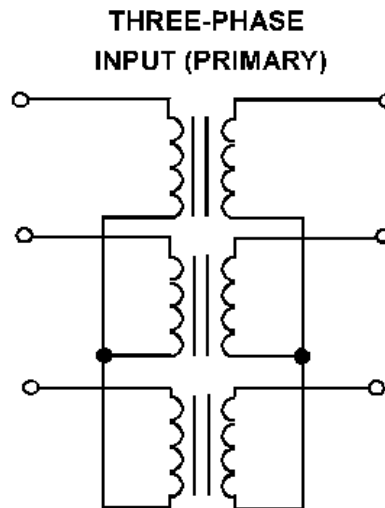
A three-phase transformer may be made up of three, single-phase transformers connected in delta, wye, or a combination of both. If both the primary and secondary are connected in wye, the transformer is called a wye-wye. If both windings are connected in delta, the transformer is called a delta-delta.

Figure 3-10 shows single-phase transformers connected delta-delta for operation in a three-phase system. You will note that the transformer windings are not angled to illustrate the typical delta ( $\Delta$ ) as has been done with alternator windings. Physically, each transformer in the diagram stands alone. There is no angular relationship between the windings of the individual transformers. However, if you follow the connections, you will see that they form an electrical delta. The primary windings, for example, are connected to each other to form a closed loop. Each of these junctions is fed with a phase voltage from a three-phase alternator. The alternator may be connected either delta or wye depending on load and voltage requirements, and the design of the system.



**Figure 3-10.—Three single-phase transformers connected delta-delta.**

Figure 3-11 shows three single-phase transformers connected wye-wye. Again, note that the transformer windings are not angled. Electrically, a Y is formed by the connections. The lower connections of each winding are shorted together. These form the common point of the wye. The opposite end of each winding is isolated. These ends form the arms of the wye.



**Figure 3-11.—Three single-phase transformers connected wye-wye.**

The ac power on most ships is distributed by a three-phase, three-wire, 450-volt system. The single-phase transformers step the voltage down to 117 volts. These transformers are connected delta-delta as in figure 3-10. With a delta-delta configuration, the load may be a three-phase device connected to all phases; or, it may be a single-phase device connected to only one phase.

At this point, it is important to remember that such a distribution system includes everything between the alternator and the load. Because of the many choices that three-phase systems provide, care must be taken to ensure that any change of connections does not provide the load with the wrong voltage or the wrong phase.

- Q14. In a three-phase alternator, what is the phase relationship between the individual output voltages?*
- Q15. What are the two methods of connecting the outputs from a three-phase alternator to the load?*
- Q16. Ships' generators produce 450-volt, three-phase, ac power; however, most equipment uses 117-volt, single-phase power. What transformers and connections are used to convert 450-volt, three-phase power to 117-volt, single-phase power?*

## **FREQUENCY**

The output frequency of alternator voltage depends upon the speed of rotation of the rotor and the number of poles. The faster the speed, the higher the frequency. The lower the speed, the lower the frequency. The more poles there are on the rotor, the higher the frequency is for a given speed. When a rotor has rotated through an angle such that two adjacent rotor poles (a north and a south pole) have passed one winding, the voltage induced in that winding will have varied through one complete cycle. For a given frequency, the more pairs of poles there are, the lower the speed of rotation. This principle is

illustrated in figure 3-12; a two-pole generator must rotate at four times the speed of an eight-pole generator to produce the same frequency of generated voltage. The frequency of any ac generator in hertz (Hz), which is the number of cycles per second, is related to the number of poles and the speed of rotation, as expressed by the equation

$$F = \frac{NP}{120}$$

where P is the number of poles, N is the speed of rotation in revolutions per minute (rpm), and 120 is a constant to allow for the conversion of minutes to seconds and from poles to pairs of poles. For example, a 2-pole, 3600-rpm alternator has a frequency of 60 Hz; determined as follows:

$$\frac{2 \times 3600}{120} = 60\text{Hz}$$

A 4-pole, 1800-rpm generator also has a frequency of 60 Hz. A 6-pole, 500-rpm generator has a frequency of

$$\frac{6 \times 500}{120} = 25\text{Hz}$$

A 12-pole, 4000-rpm generator has a frequency of

$$\frac{12 \times 4000}{120} = 400\text{Hz}$$

*Q17. What two factors determine the frequency of the output voltage of an alternator?*

*Q18. What is the frequency of the output voltage of an alternator with four poles that is rotated at 3600 rpm?*

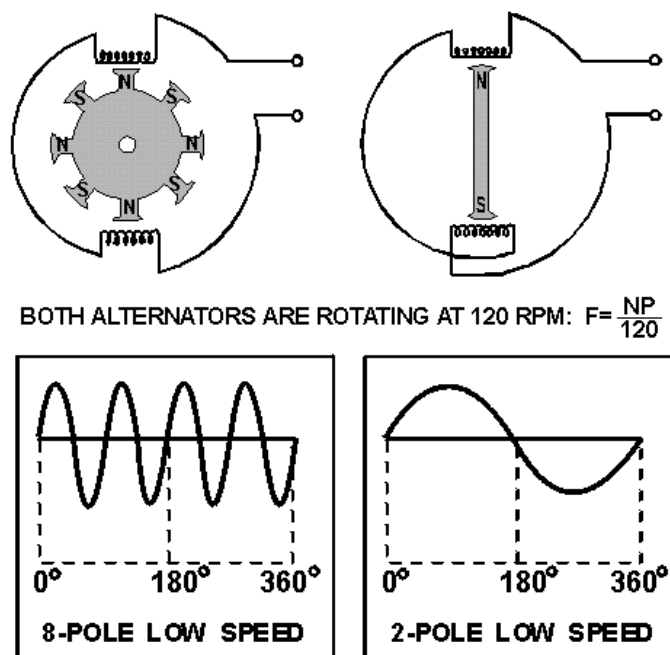


Figure 3-12.—Frequency regulation.

## VOLTAGE REGULATION

As we have seen before, when the load on a generator is changed, the terminal voltage varies. The amount of variation depends on the design of the generator.

The voltage regulation of an alternator is the change of voltage from full load to no load, expressed as a percentage of full-load volts, when the speed and dc field current are held constant.

$$\frac{E_{nL} - E_{fL}}{E_{fL}} \times 100 = \text{Percent of regulation}$$

Assume the no-load voltage of an alternator is 250 volts and the full-load voltage is 220 volts. The percent of regulation is

$$\frac{250 - 220}{220} \times 100 = 13.6\%$$

Remember, the lower the percent of regulation, the better it is in most applications.

*Q19. The variation in output voltage as the load changes is referred to as what? How is it expressed?*

## PRINCIPLES OF AC VOLTAGE CONTROL

In an alternator, an alternating voltage is induced in the armature windings when magnetic fields of alternating polarity are passed across these windings. The amount of voltage induced in the windings

depends mainly on three things: (1) the number of conductors in series per winding, (2) the speed (alternator rpm) at which the magnetic field cuts the winding, and (3) the strength of the magnetic field. Any of these three factors could be used to control the amount of voltage induced in the alternator windings.

The number of windings, of course, is fixed when the alternator is manufactured. Also, if the output frequency is required to be of a constant value, then the speed of the rotating field must be held constant. This prevents the use of the alternator rpm as a means of controlling the voltage output. Thus, the only practical method for obtaining voltage control is to control the strength of the rotating magnetic field. The strength of this electromagnetic field may be varied by changing the amount of current flowing through the field coil. This is accomplished by varying the amount of voltage applied across the field coil.

*Q20. How is output voltage controlled in practical alternators?*

### **PARALLEL OPERATION OF ALTERNATORS**

Alternators are connected in parallel to (1) increase the output capacity of a system beyond that of a single unit, (2) serve as additional reserve power for expected demands, or (3) permit shutting down one machine and cutting in a standby machine without interrupting power distribution. When alternators are of sufficient size, and are operating at different frequencies and terminal voltages, severe damage may result if they are suddenly connected to each other through a common bus. To avoid this, the machines must be synchronized as closely as possible before connecting them together. This may be accomplished by connecting one generator to the bus (referred to as bus generator), and then synchronizing the other (incoming generator) to it before closing the incoming generator's main power contactor. The generators are synchronized when the following conditions are set:

1. Equal terminal voltages. This is obtained by adjustment of the incoming generator's field strength.
2. Equal frequency. This is obtained by adjustment of the incoming generator's prime-mover speed.
3. Phase voltages in proper phase relation. The procedure for synchronizing generators is not discussed in this chapter. At this point, it is enough for you to know that the above must be accomplished to prevent damage to the machines.

*Q21. What generator characteristics must be considered when alternators are synchronized for parallel operation?*

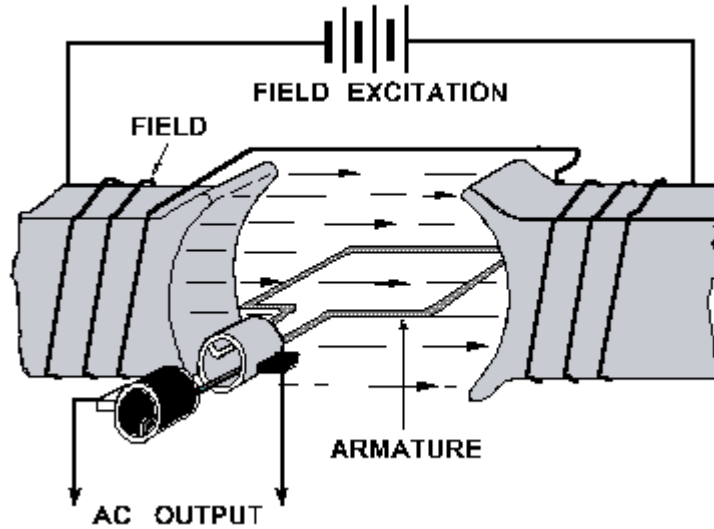
### **SUMMARY**

This chapter has presented an introduction to the subject of alternators. You have studied the characteristics and applications of different types. The following information provides a summary of the chapter for your review.

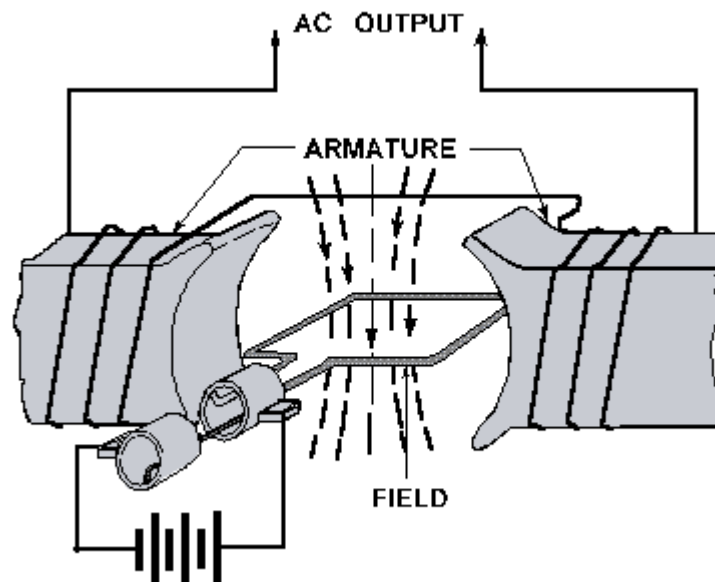
**MAGNETIC INDUCTION** is the process of inducing an emf in a coil whenever the coil is placed in a magnetic field and motion exists between the coil and the magnetic lines of flux. This is true if either the coil or the magnetic field moves, as long as the coil is caused to cut across magnetic flux lines.



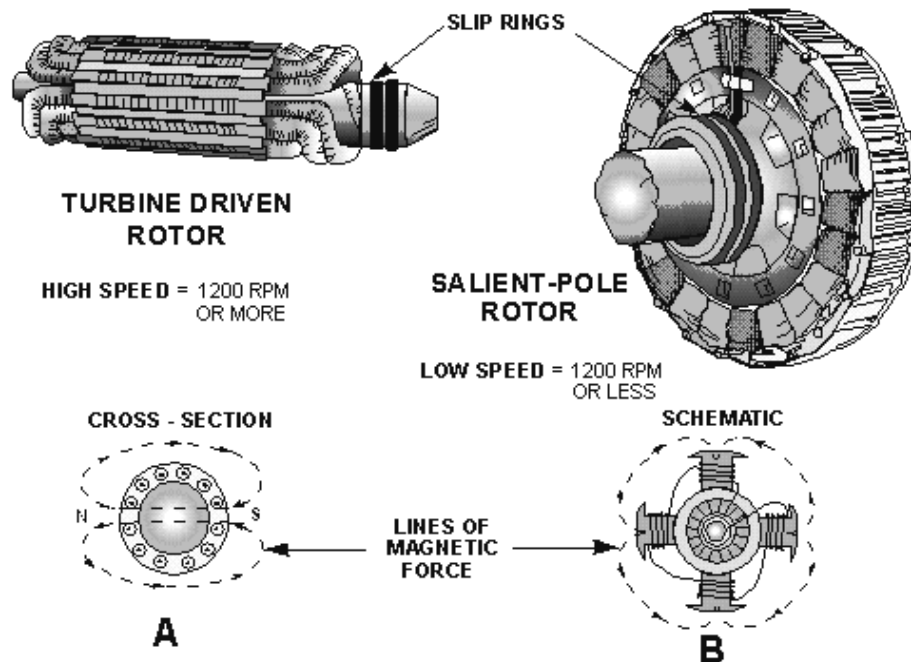
The **ROTATING ARMATURE-ALTERNATOR** is essentially a loop rotating through a stationary magnetic field. The cutting action of the loop through the magnetic field generates ac in the loop. This ac is removed from the loop by means of slip rings and applied to an external load.



The **ROTATING-FIELD ALTERNATOR** has a stationary armature and a rotating field. High voltages can be generated in the armature and applied to the load directly, without the need of slip rings and brushes. The low dc voltage is applied to the rotor field by means of slip rings, but this does not introduce any insulation problems.



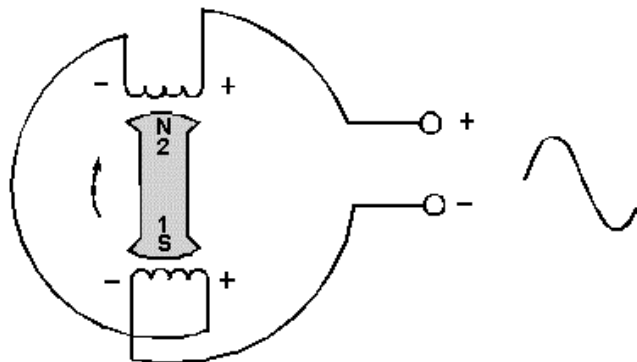
**ROTOR CONSTRUCTION** in alternators may be either of two types. The salient-pole rotor is used in slower speed alternators. The turbine driven-type is wound in a manner to allow high-speed use without flying apart.



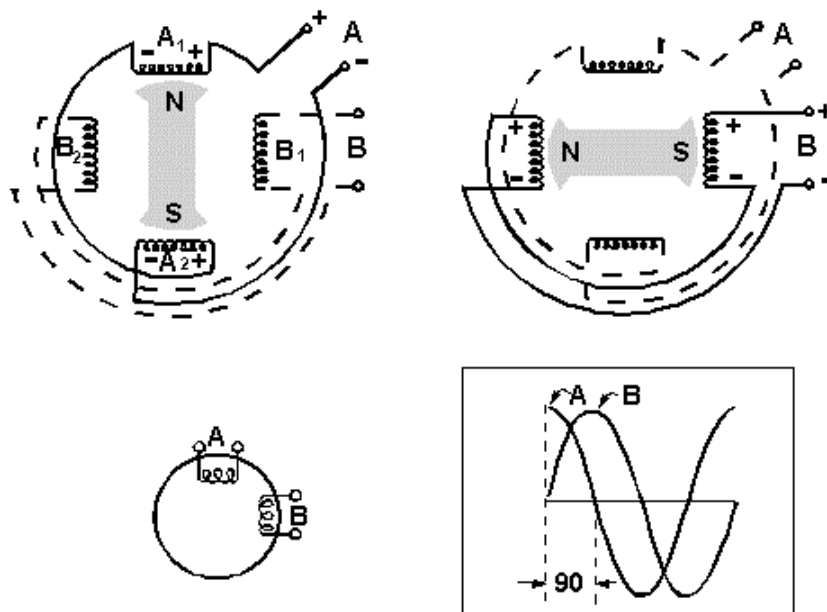
**GENERATOR RATINGS** are dependent on the amount of current they are capable of providing at full output voltage; this rating is expressed as the product of the voltage times the current. A 10-volt alternator capable of supplying 10 amperes of current would be rated at 100 volt-amperes. Larger alternators are rated in kilovolt-amperes.

**EXCITER GENERATORS** are small dc generators built into alternators to provide excitation current to field windings. These dc generators are called exciters.

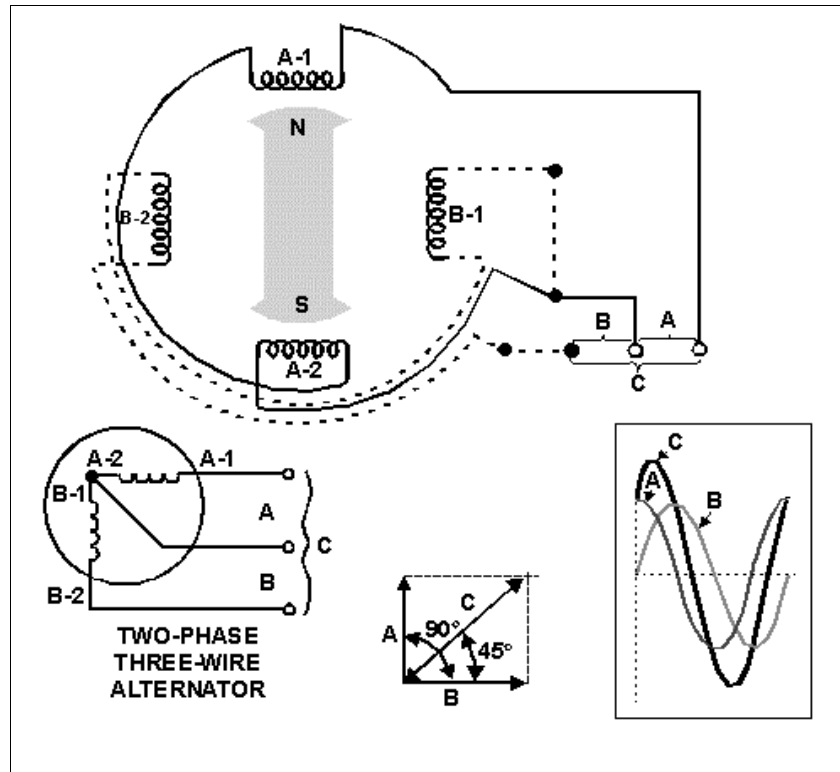
The **SINGLE-PHASE ALTERNATOR** has an armature that consists of a number of windings placed symmetrically around the stator and connected in series. The voltages generated in each winding add to produce the total voltage across the two output terminals.



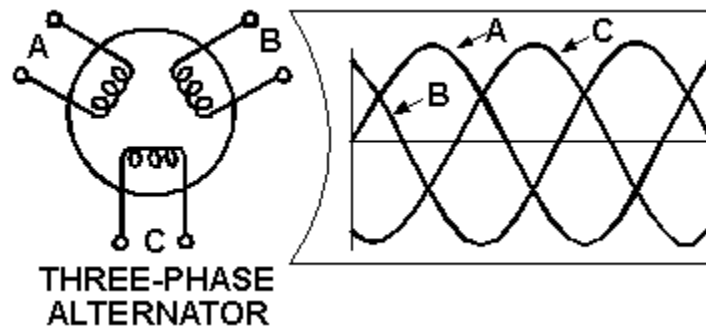
A **TWO-PHASE ALTERNATOR** consists of two phases whose windings are so placed around the stator that the voltages generated in them are  $90^\circ$  out of phase.



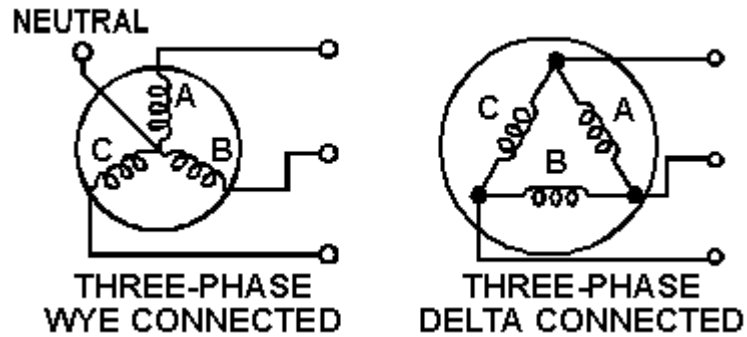
**TWO-PHASE ALTERNATOR CONNECTIONS** may be modified so that the output of a two-phase alternator is in a three-wire manner, which actually provides three outputs, two induced phase voltages, plus a vectorial sum voltage.



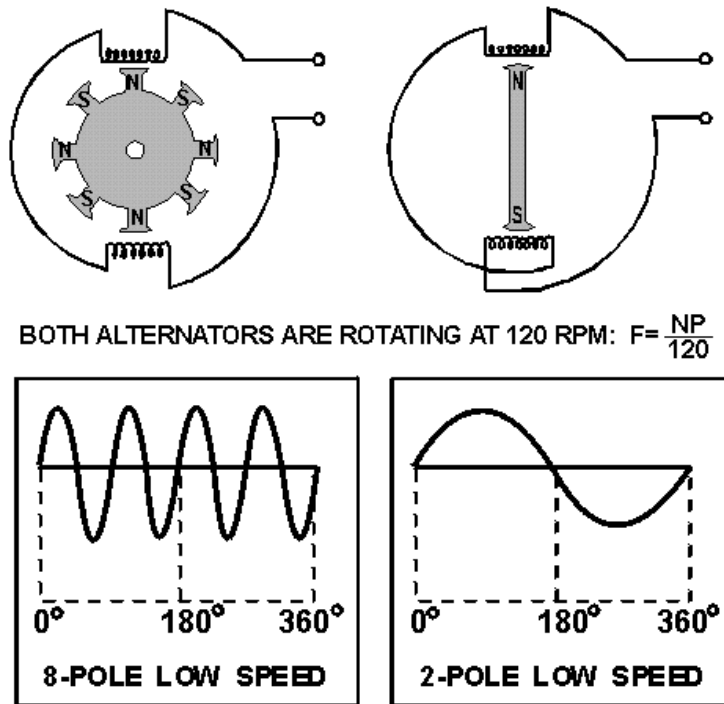
In **THREE-PHASE ALTERNATORS** the windings have voltages generated in them which are 120° out of phase. Three-phase alternators are most often used to generate ac power.



**THREE-PHASE ALTERNATOR CONNECTIONS** may be delta or wye connections depending on the application. The ac power aboard ship is usually taken from the ship's generators through delta connections, for the convenience of step-down transformers.



**ALTERNATOR FREQUENCY** depends upon the speed of rotation and the number of pairs of rotor poles.



**VOLTAGE REGULATION** is the change in output voltage of an alternator under varying load conditions.

**VOLTAGE CONTROL** in alternators is accomplished by varying the current in the field windings, much as in dc generators.

***ANSWERS TO QUESTIONS Q1. THROUGH Q21.***

- A1. A conductor and a magnetic field.*
- A2. Armature.*
- A3. Rotating armature and rotating field.*
- A4. Output voltage is taken directly from the armature (not through brushes or slip rings).*
- A5. To provide dc current for the rotating field.*
- A6. Kilovolt-amperes (volt amperes).*
- A7. Steam turbine.*
- A8. Internal combustion engines, water force and electric motors.*
- A9. One voltage (one output).*
- A10. In series.*
- A11. Placement of armature coils.*
- A12. Three.*
- A13. C is 1.414 times greater than A or B.*
- A14. Each phase is displaced 120° from the other two.*
- A15. Wye and Delta.*
- A16. Three single-phase, delta-delta, step-down transformers.*
- A17. Speed of rotation and number of poles.*
- A18. 120 Hz.*
- A19. Voltage regulation. As a percentage.*
- A20. By varying the voltage applied to the field windings.*
- A21. Output voltage, frequency, and phase relationships.*